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## MODEL MEASUREMENTS OF LAMBERTSON MAGNET END FIELD CORRECTIONS

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### SUMMARY

Measurements of the relative effective field length as a function of horizontal position (x direction in Fig. 1) were made on a model Lambertson magnet equipped with different end-field correction packs. The purpose of the measurements was to demonstrate how the end-field corrections can be made on the Tevatron Beam Abort Lambertson magnets. One answer appears to be: extend the top pole (the one with the field free hole in it) out beyond the bottom pole slightly more than a gap width and cut a taper in the bottom pole to the extent required for the final shaping of the effective field length curve.

### MOTIVATION

In the system proposed for the Tevatron Beam Abort system, the Lambertson magnets have the circulating beam in the field region rather than in the field free hole as in the conventional use of Lambertson magnets. Because of this the fields must be of machine quality with correction of end field effects. Normal dipole magnets have "end packs" that generally have some type of taper cut symmetrically into the magnet poles. The field free hole in a Lambertson magnet makes the magnet inherently asymmetric. Cutting a taper in the pole on the side with the field free hole would cut into that hole leaving some small strange corners to saturate at high fields.

The idea here, as suggested by Fred Mills, is to extend the top pole out far enough to get the corner away from the high field region and then making the correction taper on the bottom pole. Extending the top pole has been done for existing Lambertsons to shield the hole region from end fields; such an extension will give field components in the longitudinal direction even at midplane. The tapers are cut to flatten the effective field length as a function of horizontal position.

### MEASUREMENTS

To demonstrate the technique, short end packs were made for the three-foot model Lambertson magnet previously built for other tests made by Mike Harrison. Two 24" and two 6" long measurement coils were wound on 3/8" by 1/2" extruded aluminum bar. The coil signals are connected through a switch box to an integrator and digital voltmeter. With a single coil at the reference position in the magnet the integrator is

xeroed and the field turned up to the desired level. This voltage,  $V$ , is proportional to either the effective body field for the short coil or the effective field length times the body field for the long coil. Using two identical coils the signal difference is put into the integrator. Now readings are taken at each of two X positions of one of the coils giving the differences,  $\Delta V_S$ , between a reference position and the desired position.

The voltage on the integrator is given by:

$$V = \frac{N_p W}{RC} \int B dl \quad (1)$$

where;

$N_p$  = number of turns on the coils

$W$  = width of coil

$RC$  = time constant of integrator circuit

$\int B dl$  = the integral of the field times the length and is taken to be  $B_0 L$  with  $L$  the "effective length."

For the short coil inserted into the body of the magnet,  $L$  is a constant so that:

$$\frac{\Delta V_S}{V_S} = \frac{\Delta B_0}{B_0} \text{ is the body field variation.} \quad (2)$$

With the long coil:

$$\frac{\Delta V_L}{V_L} = \frac{\Delta B_0}{B_0} + \frac{\Delta L}{L} \quad (3)$$

where  $L$  is determined by the Z position of the 24-inch coil. For these measurements it was inserted 12" into the magnet from the bottom pole so that  $L \sim 13$ ".

Thus

$$\frac{\Delta L}{L} = \frac{\Delta V_L}{V_L} - \frac{\Delta V_S}{V_S} \quad (4)$$

is the effective field variation (the body field variation in this magnet is an important effect as will be seen from the body field measurements).

The test coils had 25 turns and were wound 3/8" high on 3/8" wide aluminum bars. The time constant was usually 3ms except for the highest field single coil values where 10ms was used. The coil was put in the midplane of the magnet gap.

For the present simulation 600 amperes in the single magnet coil (six turns) (normally the bottom coil in this test magnet but placed in the middle of the coil window) is at injection field level and 4000 amperes is near the extraction level of 9.2kG for a 40° Lambertson hole angle. (The test magnet has a 45° angle requiring a somewhat higher field for equivalent saturation.)

## RESULTS

Figure 2 shows the relative body fields measured across the 5-inch magnet pole. The numbered positions are 1/2" apart. The position of the 2" field free hole is also shown. The high field value shows a saturation effect under the hole. The body effects must be subtracted from the long coil data to allow one to see the end effects.

Figure 3 shows the body field variation at position seven as a function of current. This shows the saturation curve as the field value changes smoothly between the values shown in Fig. 1. The curve in Fig. 4 is the reference position voltage (proportional to B) divided by the magnet coil current. The high current values show field saturation. The drop off at the lower fields is not understood.

Figure 5 shows the effective variation of the magnet length with no extension of the upper pole and no taper on the lower pole. Saturation effects are evident at the high field level.

The pole gap is 1 3/16" so that a top pole overhang of 1.5" is approximately 1 1/4 gap widths. Figure 6 shows the effective length variation with a 1.5" overhang. Notice the improvement in the high field case compared to Fig. 5. Figure 7 shows the values with a 2.5" overhang. Only slight improvement is seen over the 1.5" case as might be expected. The field value decrease occurs mainly within the first gap width from the end of the magnet so that the effect of overhang would decrease similarly with distance.

Figure 8 shows the effect of adding a small taper (3/4" by 3/8" in y) to the bottom pole with a 2.5" overhang. This figure shows the widest minimum aperture seen so far. It is understood that the reference point is at position 4 so that all curves are forced to go through that point at zero.

The fourth curve shown in Figs. 6, 7, and 8 is the value taken at zero current in the magnet divided by the 600 ampere voltage. It shows the residual field variation.

To widen the aperture more a second deeper taper can be placed in the middle of the first. This should produce a dimple in the top of the curve thus somewhat flattening the curve. A 2" wide by 1/8" deeper taper was made and the results are shown in Fig. 9. Obviously it was overdone a bit but demonstrates the effect.

The effect of a taper alone is seen by looking at Fig. 5 without a taper or overhang and comparing it to Fig. 10 with a taper. Some improvement is seen but not the great improvement given by the overhang in Fig. 6. The values at 600 and 1500 amperes did move together however. The taper seems to effect the lower current curves but the overhang seems to be required to help the large saturation effect of the high current case. A larger taper 1.5" by .75" (twice the original one) was also tried in Fig. 11. The taper does not seem to correct the saturation of the high current case, but seems to have moved the 1500 ampere values away from the 600 ampere ones. Introducing a .5" overhang with the large taper gives the improvement seen in Fig. 12. A 1.5" overhang with the large taper produced the very nice results seen in Fig. 13. A 2.5" overhang and a 1.5" overhang with the large taper were tried at first but had some sign errors in the data. Only the 1.5" one was repeated and is shown in Fig. 13. Guessing at the sign error the corrected 2.5" data produced a picture similar to the 1.5" data but with somewhat larger variation between the different current sets.

The reference position voltage is recorded for each data set. Using the short coil value for the effective field the effective length relative to the bottom pole steel is given by:

$$L_{eff} \text{ (inch)} = \frac{V_L}{V_S} \times 6 - 12 \quad (5)$$

These values are shown in Table I. Notice the increase by top pole overhang and decrease by bottom pole taper as one would expect. A couple of data sets were repeated and show a significant variation.

## CONCLUSION

Qualitatively a solution to the endpack question has been demonstrated. A one to one and a half gap width overhang will allow the remaining corrections to be done with the bottom pole taper. The overhang probably allows one to avoid saturation of the corners near the hole providing the easiest way to solve the problem.

Reading more into the data should be done only with the knowledge of the poor condition of the test magnet. The high current value produced movement of various parts of the magnet with an assortment of sounds. The magnet pieces did not fit well together and were not square. Certainly much of the difficulty with reproducibility must be related to the mechanical problems of the magnet. For the real magnet measurement an improved mechanical system to hold the measurement coils is recommended.

ACKNOWLEDGEMENTS

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Coil Geom  
at end

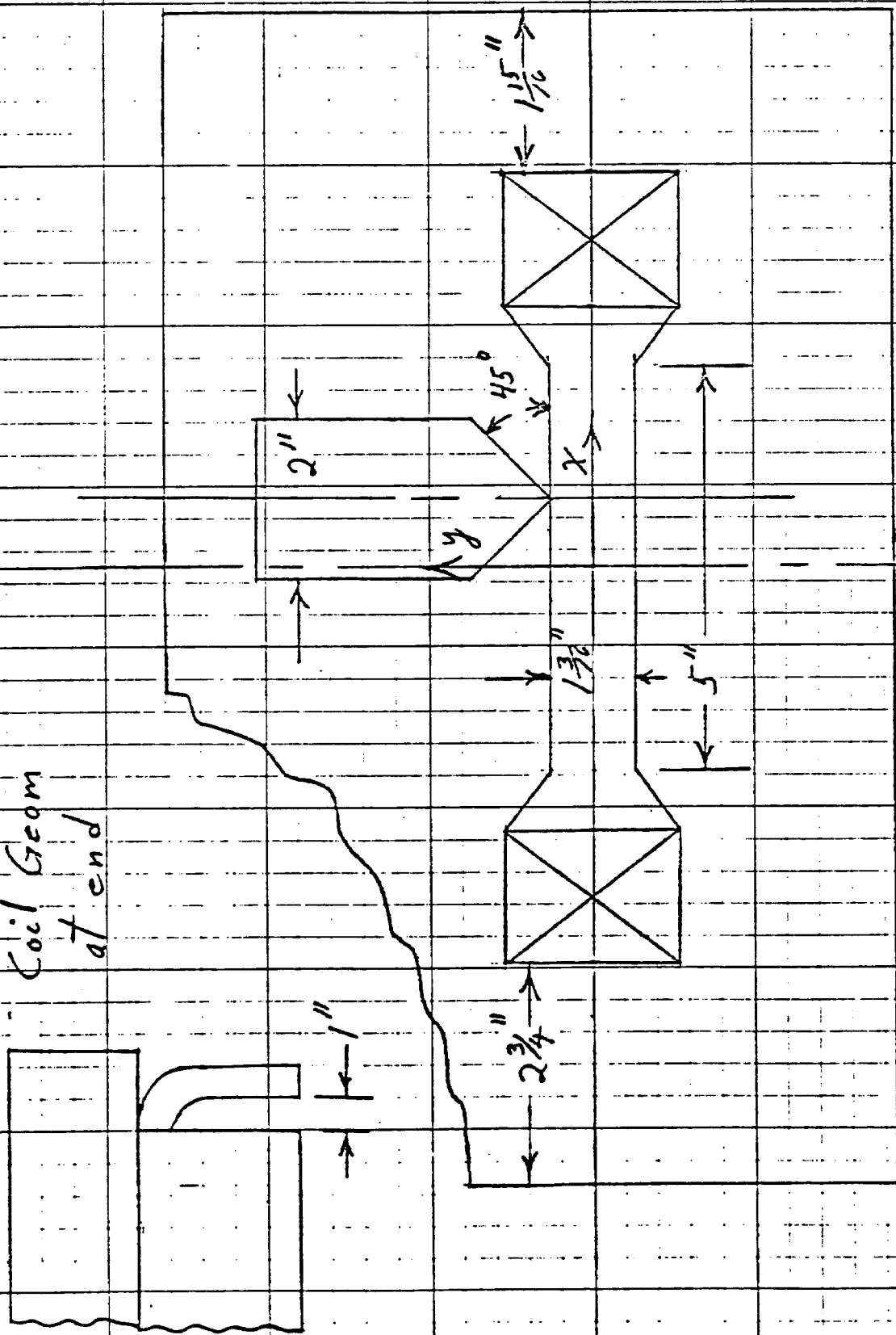


Figure 1  
Test Magnet

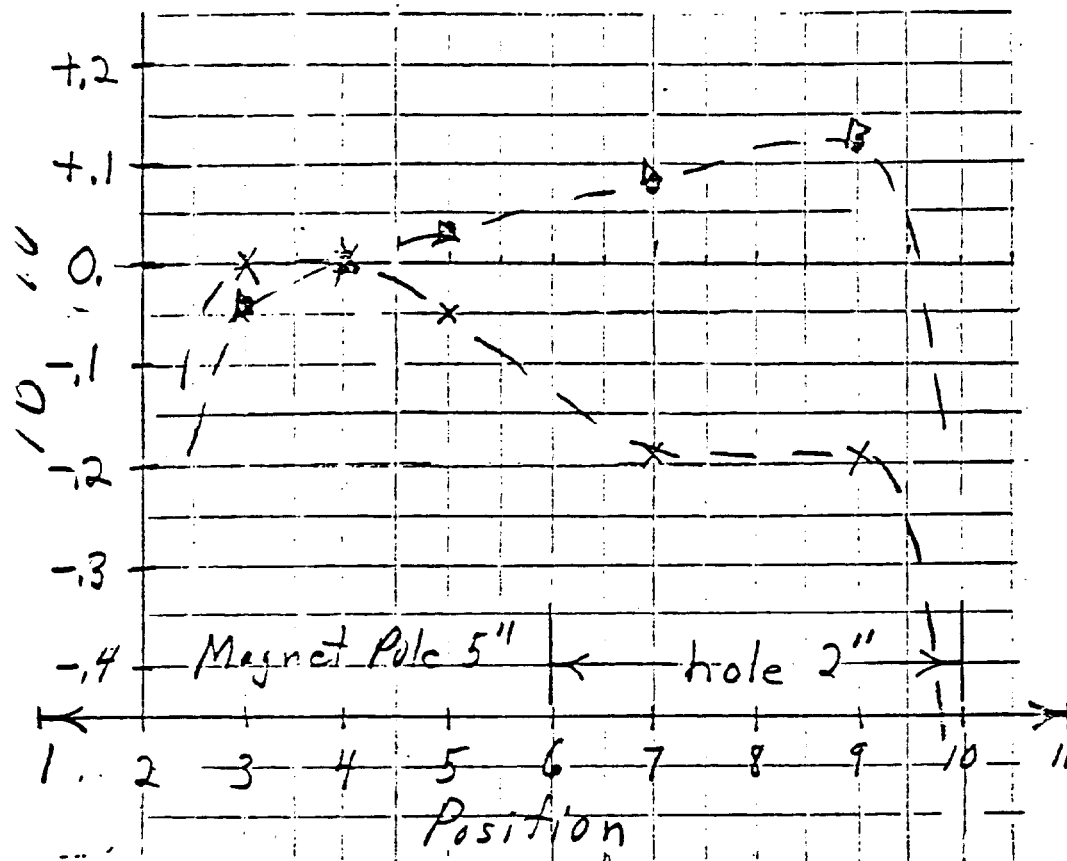


Figure 2  
Short Coil  
Body Field  
VS Position

● 600 amp 2/19/81  
Δ 1500 amp  
X 4000 amp

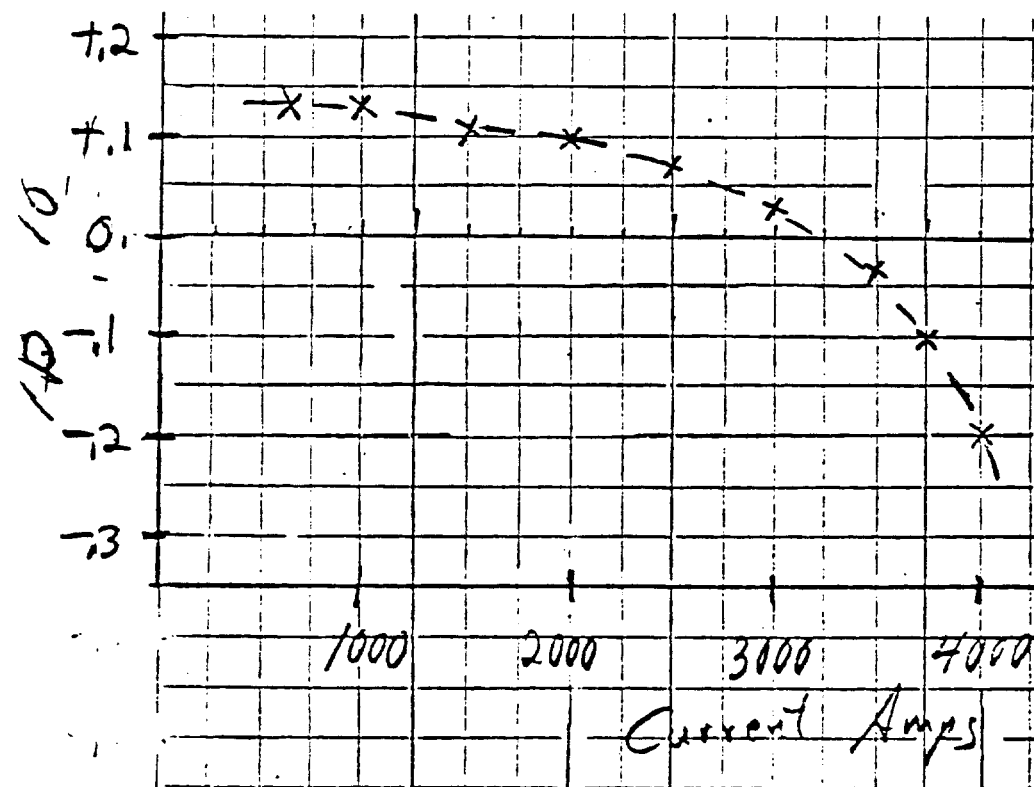


Figure 3  
Short Coil  
Body Field at Pos 7  
relative to Pos 4  
VS Magnet current

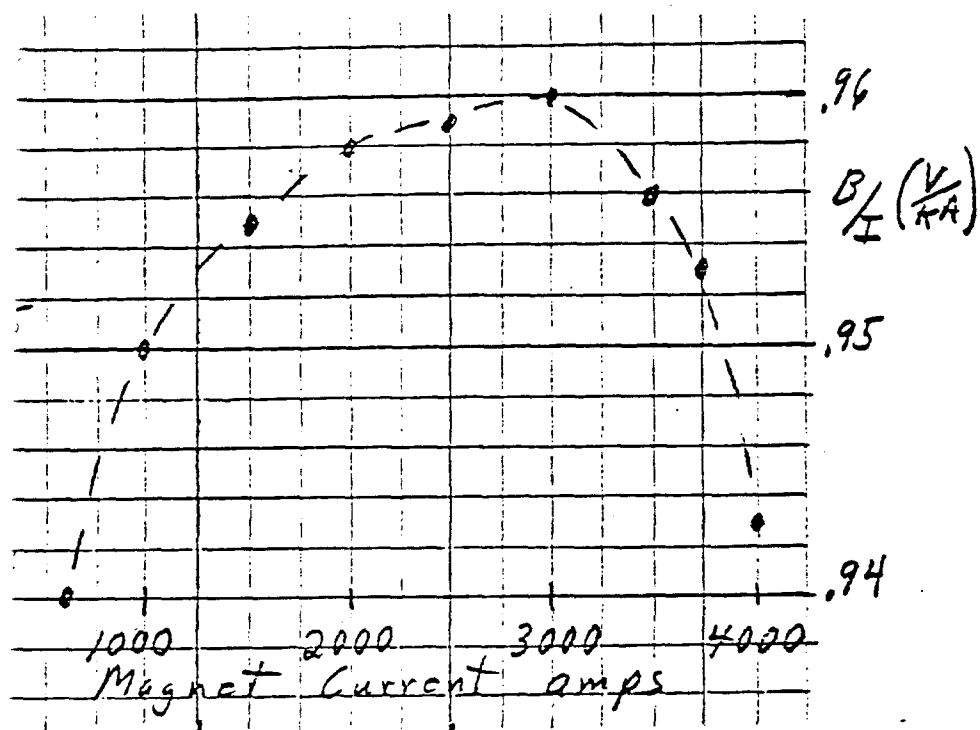


Figure 4  
Short Coil  
Body Field Current Ratio  
VS Magnet current

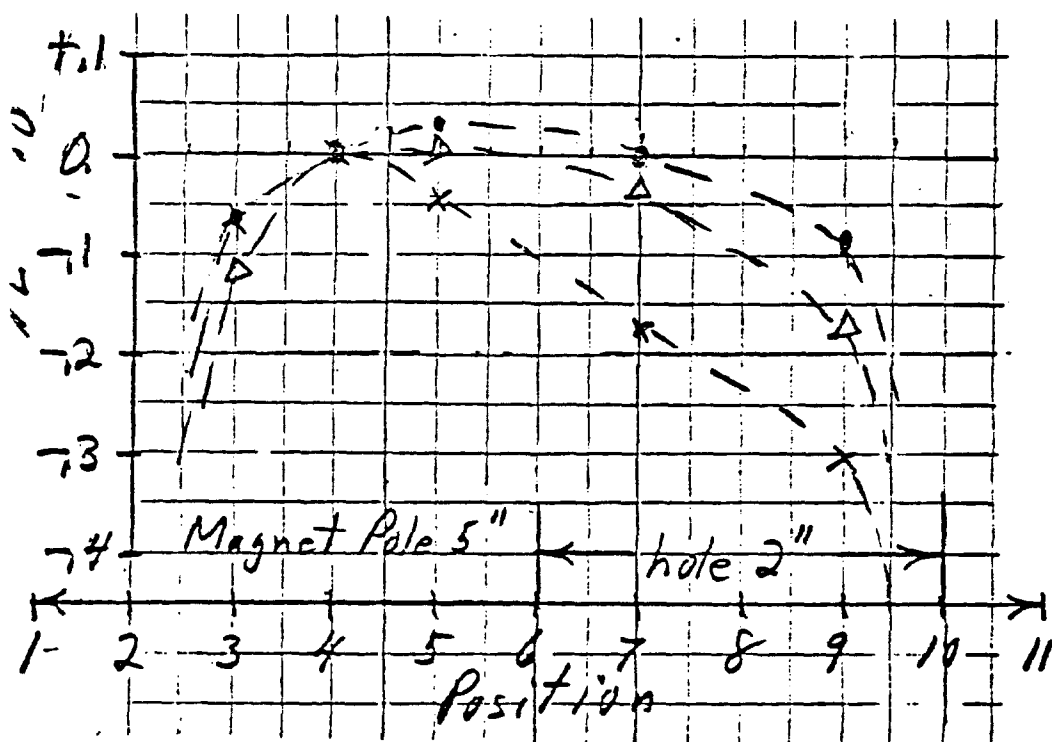


Figure 5  
Effective Length  
VS Position

Flush  
 • 600 amp 2/19/81  
 Δ 1500 amp  
 X 4000 amp

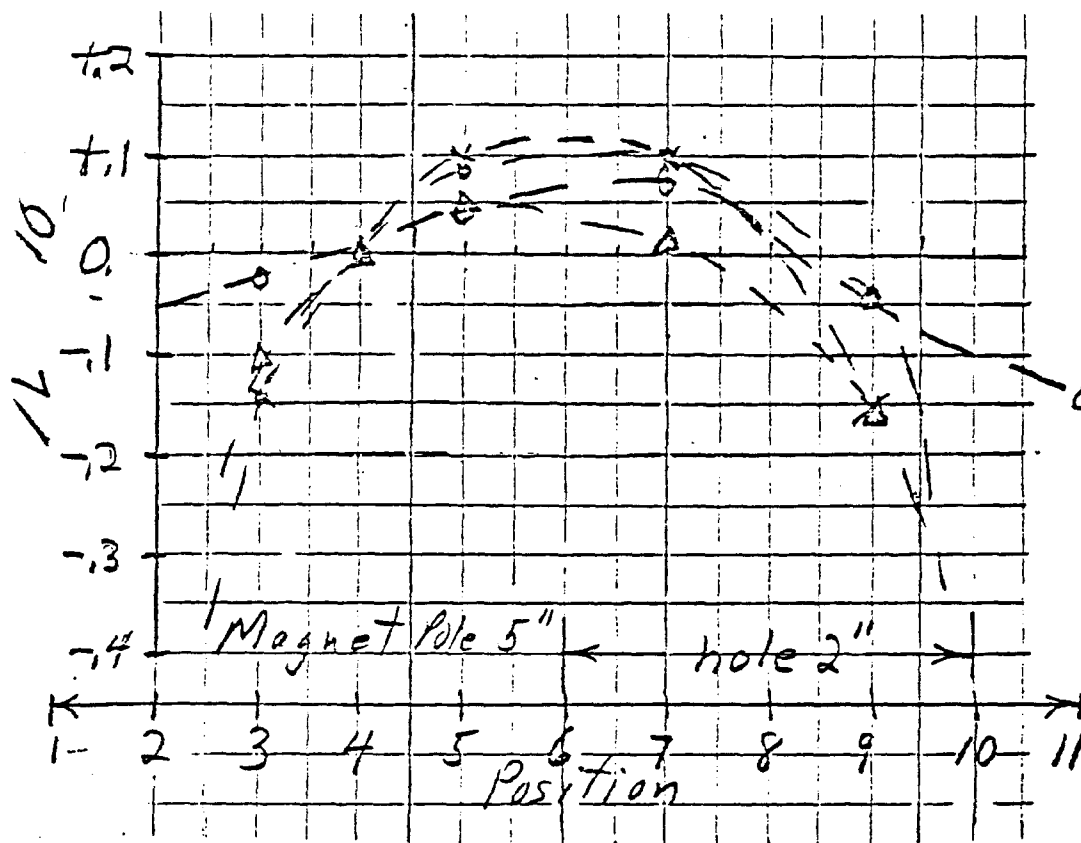


Figure 6  
Effective Length  
VS Position

1.5 inch Overhang

- 600 amp 2/19/81
- Δ 1500 amp
- X 4000 amp
- O 0 amp

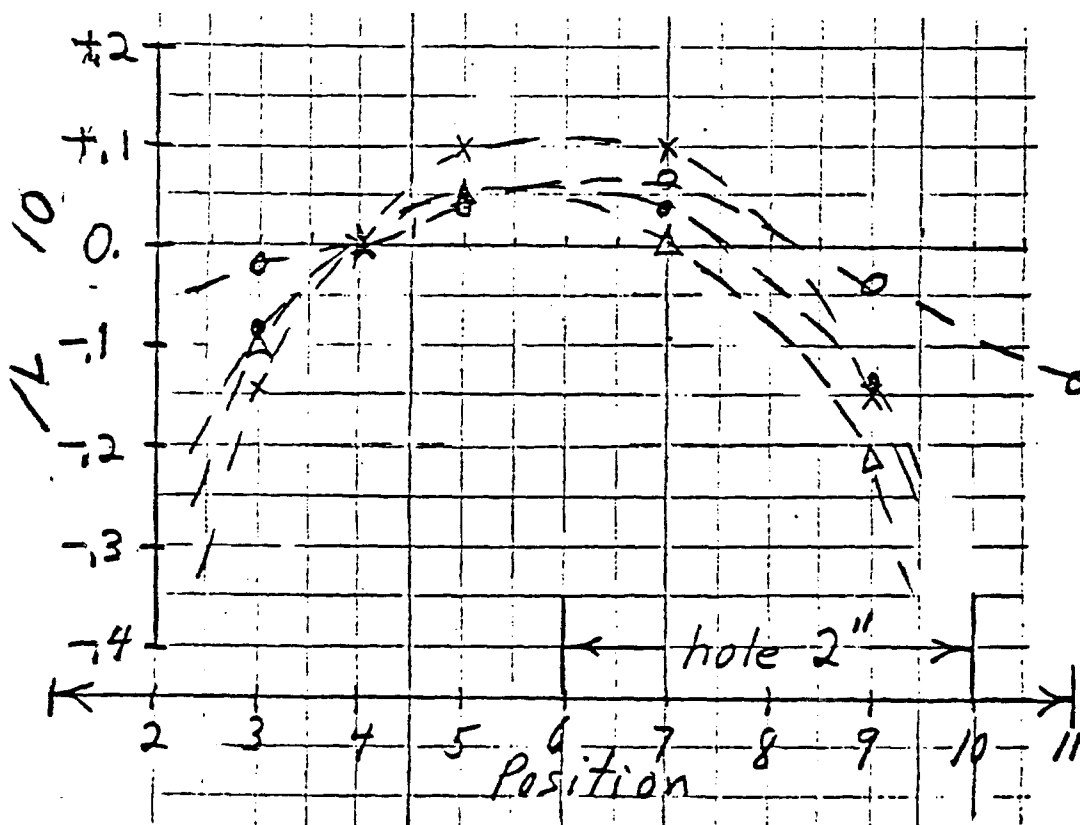


Figure 7  
Effective Length  
VS Position

2.5 inch Overhang

- 600 amp 2/19/81
- Δ 1500 amp
- X 4000 amp
- O 0 amp

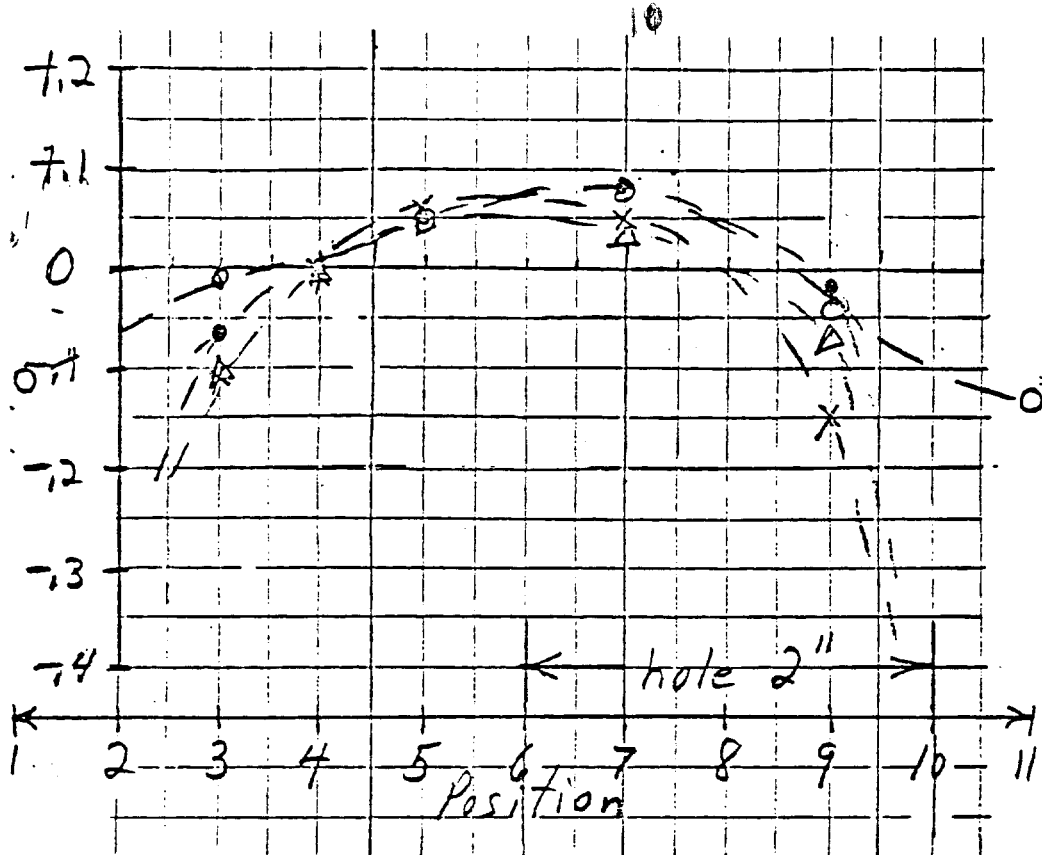


Figure 8  
Effective Length  
VS Position

2.5" O. + Taper  
 • 600 amp 2/19/81  
 Δ 1500 amp  
 X 4000 amp  
 O 0 amp

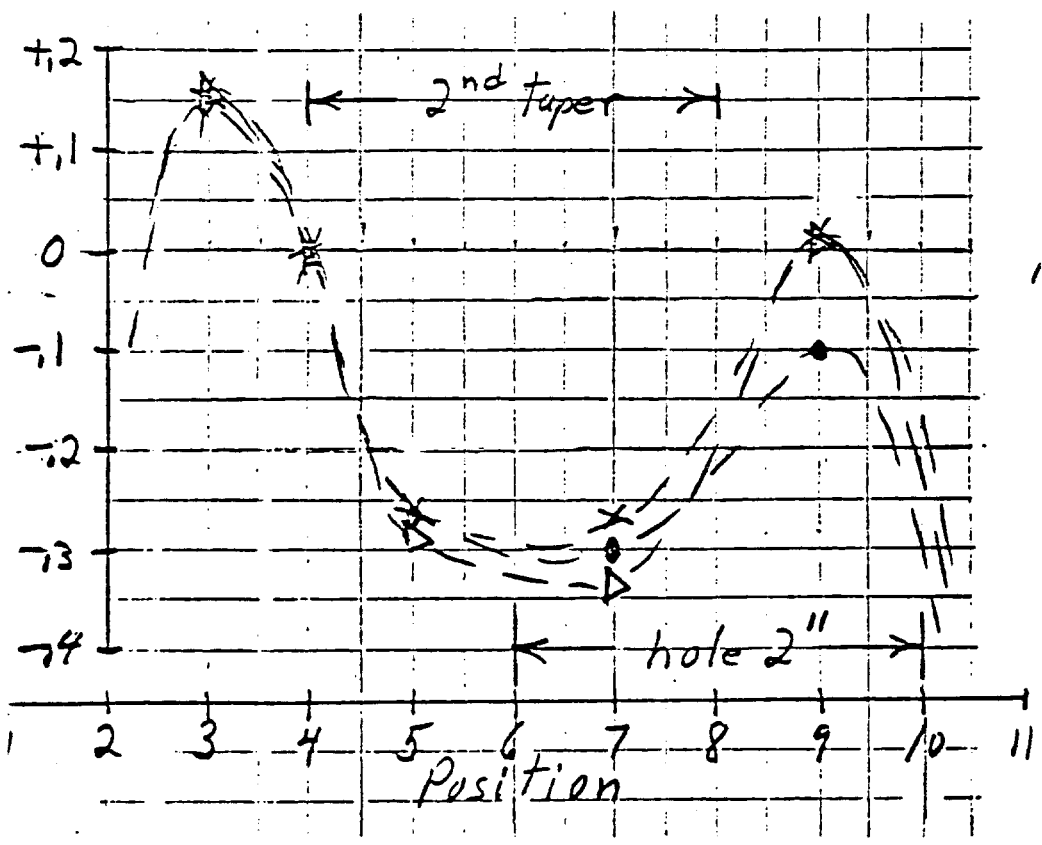


Figure 9  
Effective Length  
VS Position

2.5" O. + D. T.  
 • 600 amp 3/10/81  
 Δ 1500 amp  
 X 4000 amp

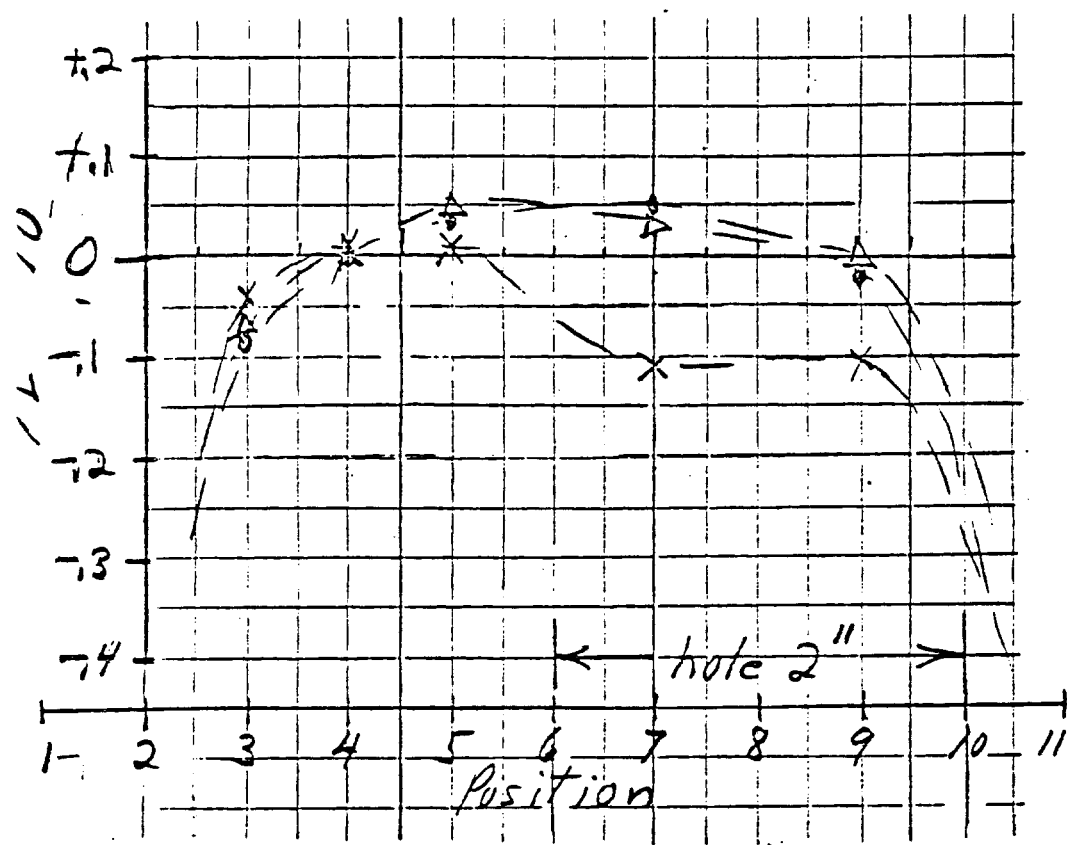


Figure 10  
Effective Length  
VS Position

Flush + Taper  
● 600 amp 3/10/81  
Δ 1500 amp  
X 4000 amp

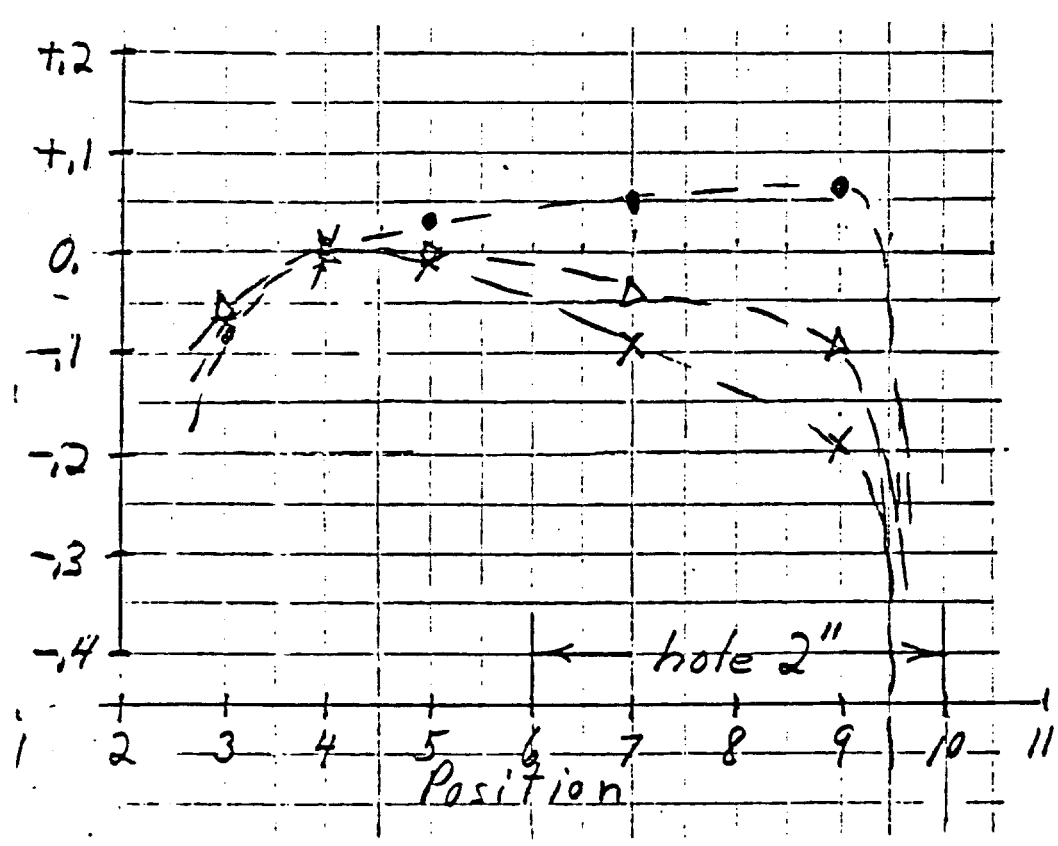


Figure 11  
Effective Length  
VS Position

Flush + L. Taper  
● 600 amp 3/13/81  
Δ 1500 amp  
X 4000 amp

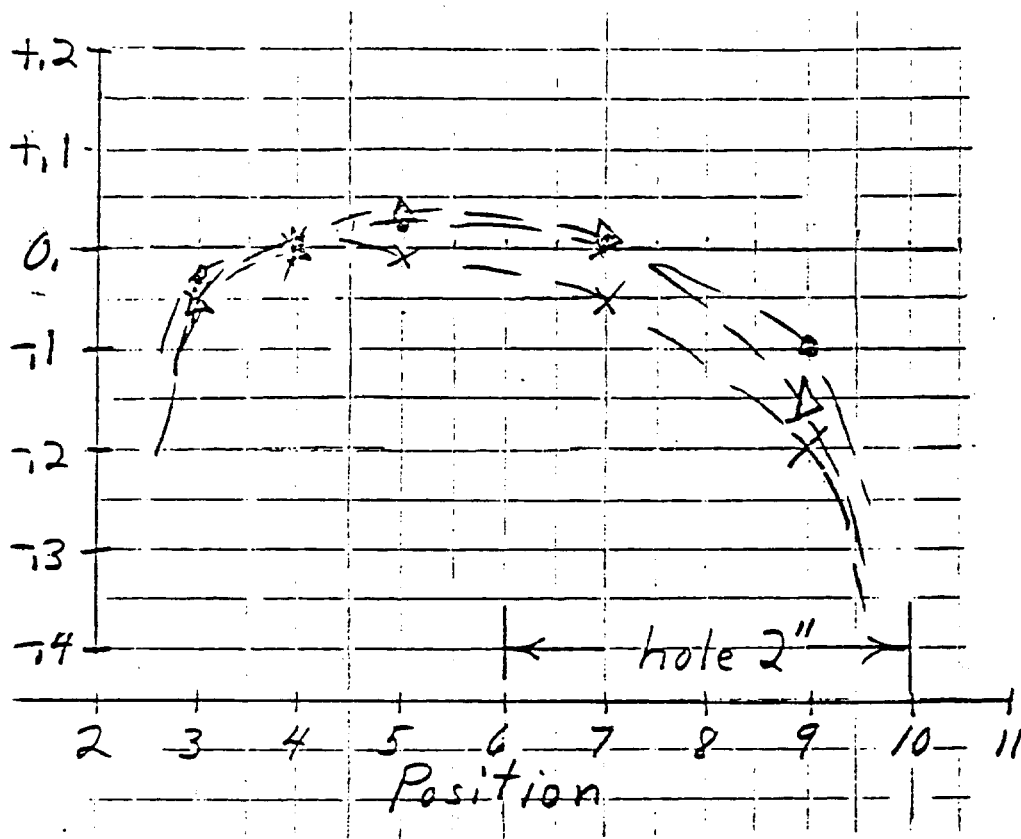


Figure 12  
Effective Length  
VS Position

.5" O. + L. T.  
• 600 amp 3/13/81  
Δ 1500 amp  
X 4000 amp

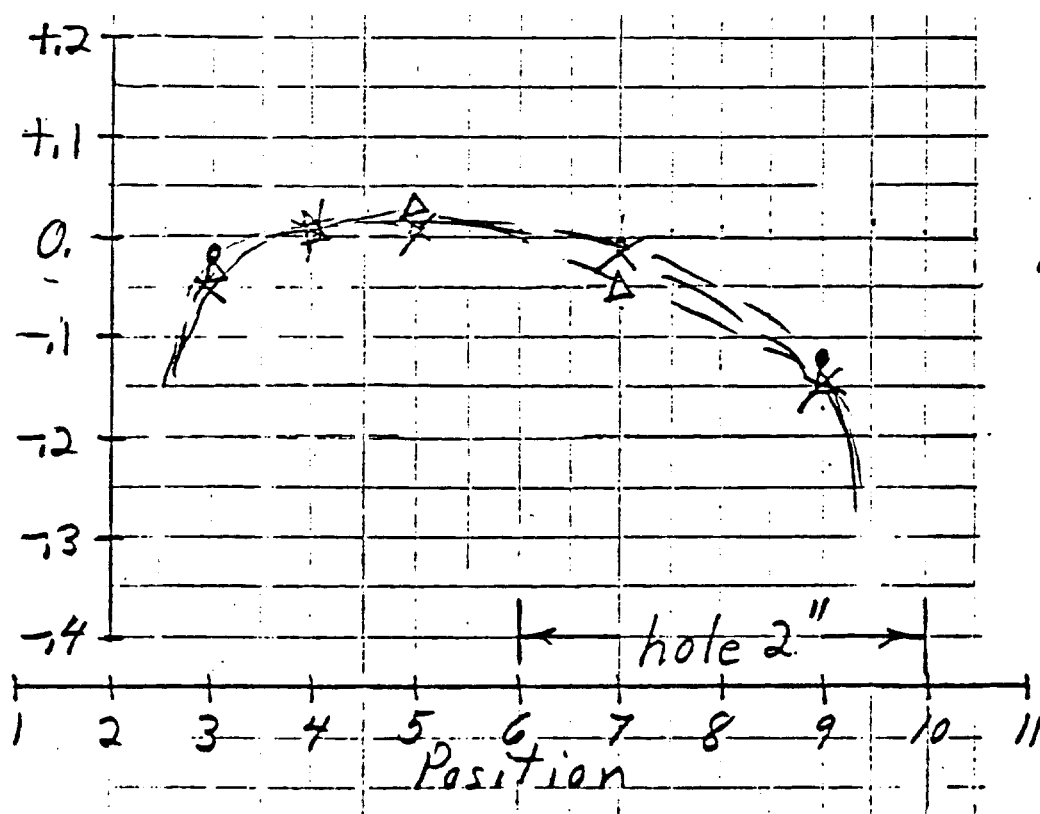


Figure 13  
Effective Length  
VS Position

1.5" O. + L. T.  
• 600 amp 3/13/81  
Δ 1500 amp  
X 4000 amp

TABLE I

Reference Position Effective Length (inches, see Eq.(5) for definition)

<u>End Condition</u>	<u>600 amp</u>	<u>1500 amp</u>	<u>4000 amp</u>
Flush	1.08	1.14	.95
1.5" Overhang	1.30	1.31	1.20
2.5" Overhang	1.45	1.43	1.23
2.5" O. + Taper	1.21	1.18	1.10
2.5" O. + Double T.	.98	1.11	1.12
Flush + S.T.	.62	.75	.89
Flush + L.T.	.13	.26	.34
	.32	.45	.57
.5" O. + L.T.	.45	.58	.70
1.5" O. + L.T.	.53	.69	.82
	.49	.62	.68
2.5" O. + L.T.	.55	.77	.84